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Description

This invention relates to a method of improving the quality of a product made from or made in contact with a body of vitreous silica.

In one aspect, the invention relates to a method of making an improved vitreous silica product, such as a crucible, a tube or a plate, having a reduced impurity content, and to a product produced by the method.

The invention also relates to an improved method for using a vitreous silica vessel for the high temperature processing of a material contained therein. Particularly valuable uses of this method of the invention are found in the treatment of molten semiconductor materials in a vitreous silica crucible (e.g. in the drawing of a single crystal of silicon).

Discussion of Prior Art

An arc moulded crucible (AMC) is normally produced by fusing a powder material under the influence of an electrical arc while the powder material (e.g. quartz powder) is held in place in a rotating mould (e.g. of water cooled metal) by centrifugal force, with or without the application of a vacuum via the mould wall(s).

A vitreous silica crucible is commonly used to contain a melt from which a single crystal is drawn. In the case of semiconductor materials, high purity is of vital importance and much effort has been, and is still being, given to avoiding impurity contamination of the melt during the crystal pulling operation. The crucible is one potential source of such contamination.

In the case of the pulling of a silicon crystal from melt in a vitreous silia crucible, alkali impurities may transfer to the molten silicon from the wall(s) of the crucible and a variety of different, often time-consuming and otherwise expensive, procedures have been proposed for the purification of the starting material used for a vitreous silica crucible to reduce the alkali impurities therein.

US—A—3303115 (corresponding FR—A—1363233) discloses a method of electrolysing a boule of fusion-produced vitreous silica material but the method disclosed is not capable of removing impurities to the levels required by this invention.

US—A—2897126 (corresponding FR—A—1123264) discloses electrolytic purification of vitreous silica but not by a process involving removal of alkali metal ions and certainly not to a level of impurity required by this invention.

According to the present invention there is proposed a method of improving the quality of a product made from, or made in contact with, a body of vitreous silica, in which alkali metal impurity ions are made to migrate away from one boundary surface of the body towards an opposite boundary surface thereof by applying a polarising potential of between 10 V/mm and 1000 V/mm thickness across the boundary surfaces of the body while the body is maintained at a temperature above 1000°C, which is characterised in that the polarising potential is maintained in the same polarity across the boundary surfaces as the body cools at least until the temperature of the body is less than 800°C, whereby the concentration of no alkali metal ion in the vitreous silica material adjacent to said one boundary surface exceeds 1.5 ppm.

Although the invention is thought to have an important commercial impact in the areas of the high temperature production of products from vitreous silica vessels and the manufacture of such vessels with reduced alkali impurity content, it will be appreciated that vitreous silica tubing whose impurity content has been reduced by electrolysis can have other useful applications than as an intermediary in the manufacture of a vitreous silica vessel.

Hence it should be appreciated that the invention also extends to the production of improved vitreous silica products (e.g. tubing) either by a one-stage process in which an ion-migrating potential is applied across the product during manufacture, or by a two-stage process in which an ion-migrating potential is applied across a heated billet prior to further processing (e.g. drawing) with or without further electrolysis during that further processing.

Once ion migration in a vitreous silica body has been achieved using the principles described herein, it would often be desirable to remove any ion-enhanced region from the body so that even if back diffusion should subsequently occur, there will be a net improvement in impurity content of the vitreous silica body.

Brief Description of the Drawings

The invention will now be more fully described with reference to the accompanying drawings, in which:

Figure 1 is a schematic indication of the invention applied to improve single crystal semiconductor material drawn from a vitreous silica crucible and as described in the following Examples 10 to 12,

Figure 2 shows a vitreous silica crucible whose purity has been improved by the method of the invention which is being processed as described in the following Examples 1 and 2,

Figure 3 shows how a vitreous silica crucible can be made in accordance with the invention in the manner described in the following Examples 3 and 4,

Figures 4 and 5 show a crucible being made in the manner described, respectively, in the following Examples 5 to 7 and Example 8, and

Figure 6 shows how the quality of vitreous silica tubing can be improved as described in the following.

Description of Preferred Embodiments

Figure 1 shows, purely schematically, a single crystal 10 of silicon being drawn from a bath 12 of molten silicon contained in a vitreous silica arc moulded crucible 14. In the usual way, the crucible 14 is contained within a graphite susceptor 16 heated by an induction coil (not shown) and the crystal 10 depends from a seed crystal 10a which has been slowly drawn upwards out of the surface of the bath 12.

A d.c. potential is applied between the seed crystal 10a and the susceptor 16 with the polarity as shown, this potential being maintained throughout the pulling operation. The magnitude of the applied potential can vary from a minimum which is sufficient to overcome contact resistances and ionisation potentials and establish a current of a few microamps, to a maximum where the high voltage causes arcing or other problems. In practice, a potential of between a few volts and a few hundred volts would normally be used. Figure 1 is further discussed in the following Examples 10 to 13.

Examples of the Invention

Example 1 (see (Figure 2)

A previously manufactured crucible 20 of 300 mm diameter with a 6 mm wall thickness was heated to 1050°C in nitrogen. An internal electrode 21, consisting of high purity carbon powder loosely filled into the crucible 20, and an external electrode was provided by a graphite holder 22 into which the crucible 20 fitted loosely. The gap between the holder 22 and the crucible 20 was filled with high purity carbon powder 23. Care was taken to ensure excess carbon powder did not cause short circuits. The upper 10 mm of the crucible protruded above the holder and internal powder fill to act as a barrier to surface tracking by the applied voltage. The holder was made the negative electrode.

The voltage was applied gradually on the crucible reaching 1050°C to keep the electrolysing current below 50 mA. After 40 minutes, the full voltage of 2.5 KV could be applied.

Electrolysis continued for 4 hours, then the temperature was allowed to drop to room temperature with the full voltage still applied.

Analysis of the crucible material after this treatment is shown in Table 1 as AMC 3.

Example 2

A second crucible was treated as in Example 1 except that the polarising voltage was switched off at 800°C as the crucible was cooling following electrolysis at 1050°C.

Analysis of the crucible is shown in Table 1 as AMC 4. From the results it can be seen that back diffusion of the alkali ions is insignificant below 800°C.

Example 3 (see Figure 3)

A further crucible 30 was heated directly in a spinning graphite mould 31 using an oxy propane flame 32 so that the crucible softened and came into intimate contact with the mould. The mould was made negative and the burner positive using a voltage of 3.8 KV. The high electrical impedance of the flame greatly reduced the voltage available for electrolysis but some improvement was measured as can be seen from the figures shown in Table 1 as AMC 10. The time of electrolysis was 5 minutes.

Example 4

A further crucible was treated as in Example 3 except that an R.F. induction plasma replaced the flame 32. The analysis of this treated crucible is shown as AMC 14 in Table 1.

Example 5 (see Figure 4)

A crucible 40 was manufactured using the spinning mould method to hold high purity quartz powder in position. Heating was with an arc 41 and the mould 42 was of water-cooled metal. An electrolysing voltage of 10 KV was applied for the final 2 minutes of heating using the arc 41 as the positive electrode and the mould 42 as the negative electrode. The analytical result is shown as AMC 21 in Table 1.

Example 6

A crucible was manufactured as for Example 5 except that an uncooled graphite mould was used in place of the water-cooled mould 42. The analytical result is shown in Table 1 as AMC 23. The improved result when compared with Example 5 is believed to be due to the higher electrical resistance of the quartz powder kept cold by the water-cooled mould in Example 5, reducing the voltage available for electrolysis.

Example 7

A crucible was manufactured as for Example 6 except that during fusion a partial vacuum of 8—7 kPa was applied between the mould 42 and the forming crucible 40 via a pipe 45.

The analytical result is shown as AMC 31. The lower impurity content in this case is believed to be due to partial ionisation of the gas in the gap between the mould and the forming crucible due to the partial vacuum and this ionised gas acting as the negative electrode.

TABLE 1

Crucible	Position	Surface	Noted impurity in ppm by weight		
			Na_2O	K_2O	Li_2O
AMC 3	Side Wall	Inner	<0.1	<0.1	<0.1
		Outer	1.5	4.2	3.3
	Base Wall	Inner	0.2	0.2	0.2
		Outer	1.6	3.3	2.8
AMC 4	Side Wall	Inner	<0.1	<0.1	<0.1
		Outer	2.5	2.0	4.4
	Base Wall	Inner	<0.1	<0.1	<0.1
		Outer	0.1	0.2	0.3
AMC 10	Mean Value	Inner	0.9	1.5	0.2
		Outer	2.2	2.0	2.0
AMC 14	Mean Value	Inner	<0.1	<0.1	<0.1
		Outer	0.2	0.4	0.2
AMC 21	Mean Value	Inner	0.9	1.2	0.2
		Outer	1.4	2.5	2.0
AMC 23	Mean Value	Inner	0.2	1.3	<0.1
		Outer	0.9	2.5	0.5
AMC 31	Mean Value	Inner	<0.1	0.2	<0.1
		Outer	0.1	0.4	0.1
AMC 33	Mean Value	Inner	<0.1	<0.1	<0.1
		Outer	0.2	0.5	<0.1
Starting Material for AMC 3, 4, 10, 14			5.6	5.4	3.8
Starting Material for AMC 21, 23, 31			1.4	2.5	3.2

Example 8 (see Figure 5)

A manufactured crucible 50 was placed over a closely fitting graphite internal mould 51 and heated externally with an oxy-propane ribbon burner 52. The temperature reached on the surface of the crucible was sufficient to remelt it.

A potential difference was applied between the burner 52 and the mould 51 of 4.5 KV. The mould was rotated at 1 RPM so that the flame swept over all the crucible. The mould was the positive electrode. During the processing it was noted that the flame was coloured by the ions being electrolysed from the crucible.

An additional result of the heating was that the outside of the crucible became glazed.

The analytical results appear in Table 1 as AMC 33.

Example 9 (see Figure 6)

A cylindrical pipe 60 of fused quartz with an external diameter of 200 mm, a length of 1500 mm and a wall thickness of 25 mm was subject to electrolysis across the wall with a potential difference of 10 KV.

An inner electrode 61 (anode) was made by coating the inner surface with a layer approximately 2 mm thick consisting of a paste of low alkali titanium dioxide (British Titan Products Ltd. — Grade A—HR) and a proprietary low alkali silica sol (Nalfloc Ltd. — "Nalcoag 1034A"). Connection to this electrode was made with a nickel chromium alloy band 62 which was a spring fit in the bore.

An outer electrode (cathode) consisted of a layer 63 approximately 2 mm thick coating the whole outer surface except the ends and consisting of a paste of ferric oxide and a silica sol. Connection to this electrode was made with an open pitch coil 64 of nickel chromium heat resisting wire.

Electrolysis was carried out at 1050°C. On reaching temperature, the voltage was gradually increased so as to avoid exceeding the current limitation of the power supply (100 ma). Maximum voltage of 10 KV was reached after 8 hours 40 minutes.

Electrolysis continued for 30 hours, when the furnace was allowed to cool naturally. The voltage was switched off when the pipe had cooled to 800°C.

The results of the electrolysis are shown as B4 in Table 2.

Example 10

The cylindrical pipe of fused quartz from Example 9 was machined externally to remove 1 mm from the bore and 3 mm from the external surface leaving a wall thickness of 21 mm. After cleaning with detergent and dilute hydrofluoric acid it was reheated in a graphite resistance furnace and drawn into tubing. Some of this tubing was reworked with flames on a glass working lathe to the form of a crucible. The analysis of the crucible is shown in Table 2 as C1.

TABLE 2

Surface		Impurity concentration in ppm by weight		
		Na_2O	K_2O	Li_2O
B4	Inner	< 0.1	< 0.1	< 0.1
	Centre	< 0.1	< 0.1	< 0.1
	Outer	13.9	4.8	8.0
Tube from B4		0.1	0.1	< 0.1
C1	Inner	< 0.1	< 0.1	< 0.1
	Outer	< 0.1	0.1	< 0.1
Starting Material for B4		8.8	4.3	4.4

Example 11 (see Figure 1)

A single crystal "puller" was modified to allow a voltage to be applied between the silicon single crystal 10a of Figure 1 and the graphite susceptor 16 during the growing operation which was carried out in Argon at 1 atmosphere gauge. After the crystal 10 had achieved the desired diameter, a voltage of 50—1000 V was applied between the crystal (positive) and the susceptor (negative). The voltage was derived from a current limited source of 0.010 A.

Results for the silicon crystal 10 are shown at S1 in Table 3.

Example 12

A single crystal was grown as for Example 11 except that a sub-atmospheric pressure of 15—20 torr was used in the puller. The maximum polarising voltage was limited to 200 V.

The results are shown in Table 3 (S2).

Example 13

A single crystal was grown as for Example 11 except that a coating of glassy carbon (obtained by the pyrolysis of propane diluted with Argon) had been made on the outside of the quartz crucible before use in order to improve the electrical contact between the crucible and the susceptor.

The results are shown in Table 3 (S3).

TABLE 3

Resistivity of Single Crystal
ohm-cm P.Type Silicon

Without polarizing Voltage		Crystal Shoulder	145
		Crystal end	115
With polarizing Voltage	S1	Crystal Shoulder	500
		Crystal end	300
	S2	Crystal Shoulder	850
		Crystal end	600
	S3	Crystal Shoulder	1250
		Crystal end	1050

From the foregoing Examples, it will be appreciated that the electrolysing temperature and time conditions are related one to the other and to the wall thickness across which the polarising potential is applied. In summary, these process conditions are preferably that the body is maintained for a time of at least 1 hour/mm wall thickness in the temperature range 1000°C—1200°C and at least 1 min/mm thickness in the temperature range 1201°—2000°C. The effective polarising potential applied across the boundary surfaces exceeds 10 V/mm thickness but not 1 KV/mm thickness.

Claims

1. A method of improving the quality of a product made from, or made in contact with, a body of vitreous silica, in which alkali metal impurity ions are made to migrate away from one boundary surface of the body towards an opposite boundary surface thereof by applying a polarising potential of between 10 V/mm and 1000 V/mm thickness across the boundary surfaces of the body while the body is maintained at a temperature above 1000°C, characterised in that the polarising potential is maintained in the same polarity across the boundary surfaces as the body cools at least until the temperature of the body is less

than 800°C, whereby the concentration of no alkali metal ion in the vitreous silica material adjacent to said one boundary surface exceeds 1.5 ppm.

2. A method as claimed in claim 1, characterised in that prior to cooling the body is maintained for a time corresponding to the thickness of the wall being polarised of at least 1 hour/mm thickness in the temperature range 1000°—1200°C and at least 1 min/mm thickness in the temperature range 1201°—2000°C.

3. The employment of the method claimed in claim 1 to improve the purity of melt contacting the inner wall of a vitreous silica containing vessel, characterised in that the polarising potential is applied via the melt in a direction to cause positive impurity ions in the vitrous silica to migrate away from said melt-contacted inner wall.

4. The method of claim 3, characterised in that the melt is a semiconductor material and the polarising potential is applied thereto via a single crystal of the semiconductor material in contact with the melt.

5. The method of claim 4, characterised in that the vitreous silica vessel has its outer surface in electrical contact with carbon and the polarising potential is applied across the wall of the vessel via the melt and the carbon.

6. The employment of the method claimed in claim 1, to reduce the concentration of impurity ions in a tube of vitreous silica characterised in that a polarising potential in the range 500 to 10000 volts is applied in the radial direction across the walls of the tube between electrically conductive coatings applied to said walls, and in that vitreous silica material is removed from both walls of the tube when the electrolysis of the tube has been completed.

7. The employment of the method of claim 1, to produce an improved vitreous silica crucible, the crucible being produced by a method which involves building up the thickness of a layer of fused vitreous silica against an electrically conducting mould member which defines one surface of the crucible, characterised in that said mould member is used as one electrode by which the polarising voltage is applied across the layer to cause impurity ion migration in one of the directions towards and away from the mould member.

8. The method of claim 7, characterised in that the other electrode for applying the polarising potential across the layer of fused vitreous silica is one of a hot gas used to fuse the layer of vitreous silica, a plasma from a torch and an electric arc.

9. The method of claim 1, characterised in that the ion migration occurs with the vitreous silica in one of an inert gas, a reducing gas and a pressure different from atmospheric pressure.

10. The employment of the method of claim 1 to purify an arc moulded crucible of vitreous silica material characterised in that one wall of the crucible is raised to a temperature in excess of 1000°C with a hot gas such as a flame or a plasma from a torch or an electric arc and a polarising potential is applied to the crucible to cause impurity ion migration from one wall into the gas.

Patentansprüche

1. Verfahren zur Qualitätsverbesserung eines aus einem Quarzglaskörper hergestellten oder in Kontakt damit hergestellten Produkt, wobei man Verunreinigungen an Alkalimetallionen von einer Grenzfläche des Körpers zur gegenüberliegenden Grenzfläche desselben wandern läßt, indem man ein Polarisationspotential zwischen 10 V/mm und 1000 V/mm Dicke an den Grenzflächen des Körpers anlegt, wobei man den Körper auf einer Temperatur von mehr als 1000°C hält, dadurch gekennzeichnet, daß man das Polarisationspotential in der gleichen Polarität an den Grenzflächen bewi der Abkühlung des Körpers aufrecht erhält, zumindest bis die Temperatur auf unter 800°C gesunken ist, so daß keine der Konzentrationen der Alkalimetallionen in dem jener ersteren Grenzfläche benachbarten Quarzglasmaterial 1,5 ppm überschreitet.

2. Verfahren gemäß Anspruch 1, dadurch gekennzeichnet, daß man vor dem Abkühlen den Körper eine der Dicke der zu polarisierenden Wand entsprechenden Dauer von mindestens 1 Std./mm Dicke in dem Temperaturbereich 1000°—1200°C und von zumindest 1 Min./mm Dicke in dem Temperaturbereich 1201°—2000°C hält.

3. Anwendung des Verfahrens nach Anspruch 1 zur Verbesserung der Reinheit einer, die Innenwand eines quarzglasenthaltenden Gefäßes berührenden Schmelze, dadurch gekennzeichnet, daß man ein Polarisationspotential über die Schmelze in solch einer Richtung anlegt, daß Verunreinigungen an positiven Ionen in dem Quarzglas von jener, mit der Schmelze in Berührung stehenden Innenwand wegwandern.

4. Verfahren nach Anspruch 3, dadurch gekennzeichnet, daß die Schmelze aus einem Halbleitermaterial besteht und man das Polarisationspotential daran mittels eines Einkristalls eines mit der Schmelze in Berührung stehenden Halbleitermaterials anlegt.

5. Verfahren nach Anspruch 4, dadurch gekennzeichnet, daß die Außenoberfläche des Quarzglasgefäßes in elektrischem Kontakt mit Kohlenstoff steht und man das Polarisationspotential über die Schmelze und den Kohlenstoff an die Gefäßwand anlegt.

6. Anwendung des Verfahrens nach Anspruch 1 zur Verringerung der Konzentration der Verunreinigungen an Ionen in einem Quarzglasrohr, dadurch gekennzeichnet, daß man ein Polarisationspotential im Bereich von 500 bis 10000 Volt in radialer Richtung an die Rohrwände zwischen elektrisch leitenden, auf

jene Rohrwände aufgebrachten Beschichtungen anlegt und daß man Quarzglasmaterial von beiden Rohrwänden nach Beendigung der Elektrolyse des Rohres entfernt.

7. Anwendung des Verfahrens nach Anspruch 1 zur Herstellung eines verbesserten Quarzglastiegels, wobei man den Tiegel mittels eines Verfahrens herstellt, das darin besteht, daß man die Dicke einer geschmolzenen Quarzglasschicht gegen eine elektrisch leitende, eine Oberfläche des Tiegels bestimmende Form aufbaut, dadurch gekennzeichnet, daß man jene Form als eine Elektrode verwendet, mittels der die Polarisationsspannung an die Schicht angelegt wird, wodurch die Verunreinigungen an Ionen in Richtung auf die Form zu oder von der Form weg wandern.

8. Verfahren nach Anspruch 7, dadurch gekennzeichnet, daß die andere Elektrode zur Anlegung des Polarisationspotentials an die geschmolzene Quarzglasschicht entweder aus dem zum Schmelzen der Quarzglasschicht verwendetem Heißgas, einem Plasmabrenner oder einem elektrischen Lichtbogen besteht.

9. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß die Ionenwanderung innerhalb des Quarzglases in einer Schutzgasatmosphäre, oder einer reduzierenden Gasatmosphäre und unter einem vom Normaldruck verschiedenen Durck erfolgt.

10. Anwendung des Verfahrens nach Anspruch 1 zur Reinigung eines lichtbogengeformten Tiegels aus Quarzglasmaterial, dadurch gekennzeichnet, daß man eine Tiegelwand auf eine Temperatur oberhalb 1000°C mittels eines Heißgases wie einer Flamme oder einem Plasmabrenner oder einem elektrischem Lichtbogen erhitzt und man ein Polarisationspotential an den Tiegel anlegt, so daß die Verunreinigungen an Ionen aus der Wand in das Gas wandern.

Revendications

1. Procédé pour améliorer la qualité d'un produit fait de ou fait au contact d'un corps de silice vitreuse, suivant lequel les ions de métaux alcalins formant impuretés sont amenés à migrer d'une première surface limite du corps vers une surface limite opposée de celui-ci par l'application d'un potentiel de polarisation de 10 V/mm à 1000 V/mm d'épaisseur entre les surfaces limites du corps, tandis que le corps est maintenu à une température supérieure à 1000°C, caractérisé en ce que le potentiel de polarisation est maintenu dans la même polarité entre les surfaces limites tandis que le corps se refroidit au moins jusqu'à ce que la température du corps soit inférieure à 800°C, afin que la concentration d'aucun ion de métal alcalin dans la matière de silice vitreuse adjacente à la première surface limite n'excède 1,5 ppm.

2. Procédé suivant la revendication 1, caractérisé en ce qu'avant le refroidissement, le corps est maintenu pendant une durée correspondant à l'épaisseur de la paroi qui est polarisée d'au moins 1 heure/mm d'épaisseur dans l'intervalle de température de 1000°C—1200°C et d'au moins 1 minute/mm d'épaisseur dans l'intervalle de température de 1201°C—2000°C.

3. Application du procédé suivant la revendication 1 à l'amélioration de la pureté d'une masse fondue venant en contact avec la paroi intérieure d'un récipient contenant de la silice vitreuse, caractérisée en ce que le potentiel de polarisation est appliqué par l'intermédiaire de la masse fondue dans une direction qui fait migrer les ions positifs d'impuretés dans la silice vitreuse à l'écart de la paroi intérieure au contact de la masse fondue.

4. Procédé suivant la revendication 3, caractérisé en ce que la masse fondue est une matière semi-conductrice et le potentiel de polarisation est appliqué à celle-ci par l'intermédiaire d'un monocristal de la matière semi-conductrice en contact avec la masse fondue.

5. Procédé suivant la revendication 4, caractérisé en ce que le récipient en silice vitreuse a sa surface extérieure en contact électrique avec du carbone et le potentiel de polarisation est appliqué à travers la paroi du récipient par l'intermédiaire de la masse fondue et du carbone.

6. Application du procédé suivant la revendication 1 à réduire la concentration en ions d'impuretés dans un tube en silice vitreuse, caractérisée en ce qu'un potentiel de polarisation de l'intervalle de 500 à 10.000 volts est appliqué en direction radiale aux faces de la paroi du tube entre des revêtements conducteurs de l'électricité appliqués sur ces faces et en ce que de la silice vitreuse est éliminée des deux faces de la paroi du tube lorsque l'électrolyse du tube a été achevée.

7. Application du procédé suivant la revendication 1, pour produire un creuset en silice vitreuse amélioré, le creuset étant fabriqué par un procédé qui consiste à augmenter l'épaisseur d'une couche de silice vitreuse fondue contre un moule conducteur de l'électricité qui définit une surface de creuset, caractérisée en ce que le moule sert d'électrode au moyen de laquelle le potentiel de polarisation est appliqué de part et d'autre de la couche pour faire migrer les ions d'impuretés dans une des directions vers et à l'écart du moule.

8. Procédé suivant la revendication 7, caractérisé en ce que l'autre électrode pour appliquer le potentiel de polarisation de part et d'autre de la couche de silice vitreuse fondue est l'un d'entre un gaz chaud utilisé pour fondre la couche de silice vitreuse, un plasma émanant d'un chalumeau et un arc électrique.

9. Procédé suivant la revendication 1, caractérisé en ce que la migration d'ions a lieu dans la silice vitreuse dans l'un d'entre un gaz inerte, un gaz réducteur et une différence de pression avec la pression atmosphérique.

10. Application du procédé suivant la revendication 1 à la purification d'un creuset en silice vitreuse moulé à l'arc, caractérisée en ce qu'une paroi du creuset est portée jusqu'à une température supérieure à

1000°C à l'aide d'un gaz chaud tel qu'une flamme ou un plasma émanant d'un chalumeau ou bien un arc électrique et un potentiel de polarisation est appliqué au creuset pour provoquer la migration des ions d'impureté à partir d'une paroi dans le gaz.

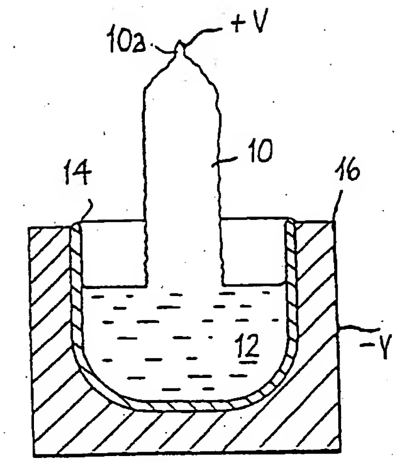

FIG.1

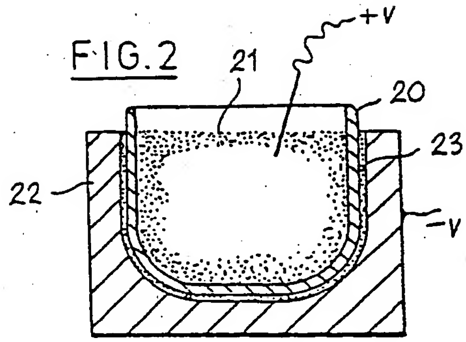

FIG.2

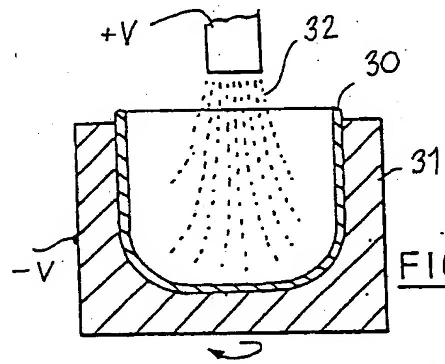

FIG.3

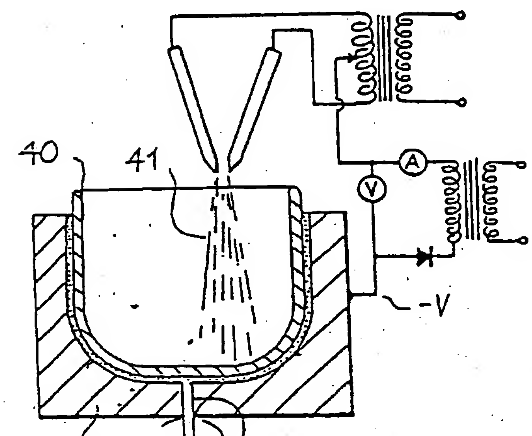

FIG.4

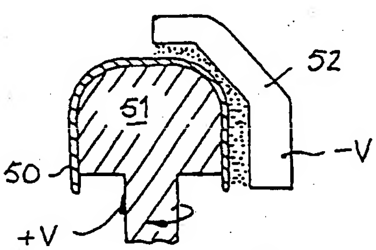

FIG.5

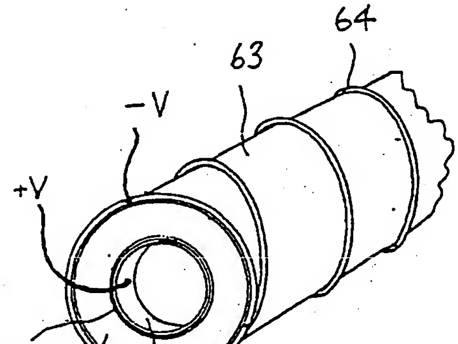

FIG.6